A NOTE ON NON-SUPERSYMMETRIC OPEN-STRING ORBIFOLDS WITH A QUANTISED B_{AB} *

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Abstract In this short note we review the main features of open-string orbifolds with a quantised flux for the NS-NS antisymmetric tensor in the context of the open descendants of non-supersymmetric asymmetric orbifolds with a vanishing cosmological constant.

Recently we have analysed in some detail the complete structure of the one-loop amplitudes for open strings [1, 2] on orbifolds [3] with a quantised NS-NS antisymmetric tensor background [4], thus extending the results in [5]. Besides recovering the expected rank reduction for the Chan-Paton (CP) gauge group, we were led to identify the discrete Wilson lines of [6] with the signs γ_ϵ that enforce a correct normalisation of the Möbius amplitude. In particular, for Z_2 orbifolds, they allow one to connect continuously $\mathrm{U}(n)$ groups to $\mathrm{Sp}(n) \otimes \mathrm{Sp}(n)$ groups. In this brief note we want to reconsider the non-supersymmetric type I vacua with vanishing cosmological constant discussed in [7, 8] in the spirit of [4]. We refer to the original papers for more details and for references.

Non-supersymmetric vacua with a vanishing cosmological constant can be obtained as asymmetric orbifolds of type II and/or type I superstrings. The simplest instance of these models can be obtained consid-

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ering the generators [9]

$$
\begin{aligned}
f &= [(-1^4,1;1^5),(0^4,v_{\rm L};\delta^4,v_{\rm R}),(-1)^{F_{\rm R}}]\,,\\
g &= [(1^5;-1^4,1),(\delta^4,w_{\rm L};0^4,w_{\rm R}),(-1)^{F_{\rm L}}]\,.
\end{aligned} \tag{1.1}
$$

The first entry in the square brackets denotes rotations, the second denotes shifts on the internal compactification lattice while the third corresponds to the space-time fermion-number. The shift δ acts as a Z_2-shift, whereas $v_{\rm L,R}$ $(= w_{\rm R,L})$ act as an A_2 shift [10] on the fifth coordinate. The asymmetric nature of the orbifold together with level matching, require that the internal 4d lattice split into a product of four circles at the radius of SU(2) enhanced symmetry. Actually, the algebra of the generators (1.1) reveals that f and g generate a non-abelian space group orbifold S [11]. The restriction to the point group $\overline{P} = S/\{f^2,g^2\}$, with f^2 and g^2 pure translations, effectively changes the lattice to an SO(8) lattice, thus introducing a non-vanishing background for the B-field

$$
B = \frac{\alpha'}{2}\begin{pmatrix} 0 & -1 & 0 & 0\\ 1 & 0 & -1 & -1\\ 0 & 1 & 0 & 0\\ 0 & 1 & 0 & 0\end{pmatrix}
$$

with rank $r=2$.

We have already noticed in [8] how the choice of the internal SO(8) lattice is crucial in order to get a consistent result. In fact, the orbifold that we are considering can be thought as an f (or g) projection of the supersymmetric T^4/Z_2 orbifold generated by fg, with the T^4 corresponding to the SO(8) lattice. The resulting torus amplitude

$$
\mathcal{T}_0 \sim |V_4O_4|^2 + |S_4S_4|^2 - (O_4V_4)(\bar{C}_4\bar{C}_4) - (C_4C_4)(\bar{O}_4\bar{V}_4) + \ldots
$$

is then consistent with the generic Klein bottle amplitude[1] (that, roughly speaking feels only the left-right symmetric generator fg) [4]

$$
\tilde{\mathcal{K}}_0 \sim \left[\sqrt{v} + \frac{2^{-r/2}}{\sqrt{v}}\right]^2 (V_4O_4 - S_4S_4) + \left[\sqrt{v} - \frac{2^{-r/2}}{\sqrt{v}}\right]^2 (O_4V_4 - C_4C_4)
$$

only for an internal SO(8) lattice, where the volume $v=\frac{1}{2}$ and $r=2$. Thus $\tilde{\mathcal{K}}_0$ contains only those states that in $\mathcal{T}_0$ are combined with their antiholomorphic counterparts. The same phenomenon also presents itself in the open sector, upon identification of Neumann and Dirichlet

[1] In our case the spinors have a flipped chirality, since the supersymmetric Z_2 generator fg contains $(-1)^{F_{\rm L}+F_{\rm R}}$ together with the standard inversions.

CP charges as a result of modding out by the T-duality contained in f. As a result of the action of f, the CP gauge group is reduced further and turns into in a single U(8) factor [7, 8]. Actually, this is the case if we break the residual internal global $\mathrm{SO}(4)^2$ symmetry by introducing discrete Wilson lines in the Möbius amplitude, thus affecting the $P = T^{\frac{1}{2}} S T^2 S T^{\frac{1}{2}}$ transformation, that acts on the real hatted characters [6, 4]. Let us analyse the massless contribution to the transverse-channel Möbius amplitude:

$$\tilde{\mathcal{M}}_0 \sim -\tfrac{2}{2}(M_1 + M_2)[(\hat{V}_4 \hat{O}_4 - \hat{S}_4 \hat{S}_4)\hat{O}_4 \hat{O}_4 - (\hat{O}_4 \hat{V}_4 - \hat{C}_4 \hat{C}_4)\hat{V}_4 \hat{V}_4]\,,$$

where with have explicitly written the contribution of the internal bosons. On the SO(4) (hatted) characters $(\hat{O}_4, \hat{V}_4, \hat{S}_4, \hat{C}_4)$, the P matrix acts as $\mathrm{diag}(\sigma_1, \sigma_1)$, with σ_1 the first Pauli matrix. As a result, the space-time vector contributes to

$$\mathcal{M}_0 \sim \tfrac{1}{2}(M_1 + M_2)[(\hat{V}_4 \hat{O}_4 - \hat{S}_4 \hat{S}_4)\hat{O}_4 \hat{O}_4 - (\hat{O}_4 \hat{V}_4 - \hat{C}_4 \hat{C}_4)\hat{V}_4 \hat{V}_4]$$

thus calling for a product of symplectic gauge groups $\mathrm{Sp}(8) \otimes \mathrm{Sp}(8)$, consistently with the tadpole conditions. The resulting model is still supersymmetric at all mass levels in the open sector, while it is non-supersymmetric in the closed sector. This has to be contrasted with the recently proposed scenario [12, 4] where supersymmetry is unbroken in the bulk (at any mass level) but is broken on branes, where a positive cosmological constant is generated at one loop.

The U(8) model of [7, 8] is obtained introducing in $\tilde{\mathcal{M}}$ discrete Wilson lines, that result in primed SO(4) characters associated to the internal lattice [6, 4]:

$$\begin{aligned} \hat{O}_4 = \hat{O}_2 \hat{O}_2 - \hat{V}_2 \hat{V}_2 \quad &\rightarrow \quad \hat{O}'_4 = \hat{O}_2 \hat{O}_2 + \hat{V}_2 \hat{V}_2\,, \\ \hat{V}_4 = \hat{O}_2 \hat{V}_2 + \hat{V}_2 \hat{O}_2 \quad &\rightarrow \quad \hat{V}'_4 = \hat{O}_2 \hat{V}_2 - \hat{V}_2 \hat{O}_2\,, \end{aligned}$$

whose P transformation is now given by the Pauli matrix σ_3 acting on $(\hat{O}'_4, \hat{V}'_4)$. As a result

$$\mathcal{M}_0 \sim -\tfrac{1}{2}(M + \bar{M})[(\hat{O}_4 \hat{V}_4 - \hat{C}_4 \hat{C}_4)\hat{O}'_4 \hat{O}'_4 - (\hat{V}_4 \hat{O}_4 - \hat{S}_4 \hat{S}_4)\hat{V}'_4 \hat{V}'_4]\,,$$

consistently with a unitary CP gauge group.

Although this latter choice has a sensible "geometric" 6d decompactification limit, it is not naturally related to the rational SO(8) internal lattice. In fact, it is the $\mathrm{Sp}(8) \otimes \mathrm{Sp}(8)$ model that, in the 6d decompactification limit, leads to the $\mathrm{Sp}(8)^4$ model of [2, 6, 13] pertaining to the rational SO(8) lattice.

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